Low cost bio-oil production using a new pyrolysis system and its integration with an efficient rotary engine

Peter B. Fransham
Encon Enterprises Inc. 1391 Normandy Crescent, Ottawa, Ontario, K2C 0N4
Fax: 613-228-7329; pfransham@sympatico.ca

From 1988 to 1995 Encon designed and experimented with a fluid bed, fast pyrolysis system. After numerous attempts to improve on the efficiency and improve on the process, it became evident that the system would not scale up because of the limited amount of heat that could be stored in the fluidizing gas stream. In 1994 Encon departed from the standard pyrolysis methods and started investigating the feasibility of a heated auger reactor. Encon built a bench scale auger reactor specifically to remove pentachlorophenol (PCP) wood preservatives from Southern Yellow Pine. The testing phase met the objectives and set the stage for subsequent developments.

The next major development in heated auger pyrolysis occurred in 1998 when Encon designed and built a crumb rubber drying plant for a client. Scale-up occurred in two steps. The first consisted of scaling from the 1 kg/hr bench model to 150 kg/hr. After extensive testing, the pilot plant was further scaled up to 24 tonnes per day and performed as designed. While the crumb rubber plant does not operate at pyrolysis temperatures, the feasibility of heat transfer from a hot auger shell to the interior sections was proven.

The above mentioned applications did not force the system to operate at high enough temperatures to liquefy the feed. Encon's original fluid bed demonstration plant was designed to operate at 520 ^oC and this temperature was taken as a starting point for heated auger pyrolysis. Initial testing at 520 ^oC yielded over 50% gas and under approximately 25% liquid. The liquid component had a water content of over 60%. These preliminary results were far from successful from a pyrolysis standpoint. The combination of high combustible gas yield and mostly water suggested that the apparatus was operating as a gasifier and not a biomass to liquid pyrolysis unit. Experimentation at lower temperatures confirmed this hypothesis. As the temperature dropped, the liquid yield increased up to a maximum of 56% at 390 ^oC. The water content is still relatively high for a bio-oil; 40% and the HHV is lower at 13.2 MJ/kg than bio-oil produced from oak sawdust that has been reported in the literature.

The auger design does not use a recycle gas blower and therefore the parasitic electrical requirements for the process are a fraction of those required by other systems. The blower alone can require several hundred horsepower for a 100 tonne per day plant. It is estimated that existing pyrolysis systems can require up to 20% of the electricity generated by a 2.5 MW biomass to electricity system. With the elimination of the blower came a complementary reduction in the size of the condensing system; a significant capital cost saving. The bench scale apparatus uses a first stage cold wall condenser and 82% of the liquid condensed in this column. A venturi scrubber removed an additional 14% of the condensable gas and the demister and filter captured 4%. Speculation is that the high gas velocity present in recycle systems atomise the bio-oil to a smaller droplet size and make it more difficult to condense. Without the recycle gas stream, velocities are lower and the vapours appear to condense more easily.

Scaling up the heated auger and ensuring heat transfer to the centre of the auger is the subject of a forthcoming patent. It is expected that a filing date will be received by the conference date and a detailed disclosure of the design will be made during the conference presentation. Testing of the patent-applied-for design is in progress and indications are that this design will produce higher quality oil, and increased liquid yield more in line with existing fluid bed and transport technologies. Preliminary engineering and costing for a 125 tonnes per day plant has been made and a detailed economic model has been prepared. Bio-oil from a heated auger system will cost in the order of US$0.03 per litre or about

US$0.12 per US gallon. When placed on an equal energy basis with #2 fuel, the bio-oil is expected to cost in the vicinity of US$0.08 per litre. The same model was used to estimate the cost of bio-oil from competitive systems and is significantly less expensive

Producing a low cost bio-oil is an accomplishment, but conversion to useful power is another. A review of the literature showed that bio-oil does not autoignite and hence either a high cetane fuel must be co-injected or a spark ignition engine must be used. A 2.5 MW turbine capable of burning bio-oil has been developed and tested on a very limited basis. A review of the market suggests that most applications for biomass to electricity would be in the 50 – 500 kW range. Since the heated auger design can be economically scaled from a few kilograms per hour up to several tonnes per hour, it was decided that an internal combustion ignition engine would best match with the technology. The rotary engine manufactured by Rotary Power International was chosen as the best available technology for bio-oil combustion. Rotary Power's engines, unmodified, will operate on a wide variety of fuels including natural gas, propane, gasoline, kerosene, diesel fuel, and similar liquid fuels and fuels derived from biomass. They will operate on natural gas or other gaseous fuels without sacrificing power or fuel efficiency. The injection and ignition systems allows the engine to operate using heavy fuels over a wide horsepower and speed range without the excess weight required by a reciprocating engine. The engine is configured to operate at high efficiency on heavy fuels, which include diesel and jet fuel and their derivatives.

A rotary engine's compact power train results in superior size and weight characteristics for a given power output. Substantially smaller and lighter engines with very high power density are obtainable. Further enhanced power density is achieved by turbo-compounding the exhaust from the rotary engine. Rotary Power's rotary engine design simplicity and modularity, reduce manufacturing costs and spare parts inventory.

Due to its unique geometry, the rotary engine is able to operate at a very lean fuel to air ratio compared to reciprocating engines. This ratio results in relatively low emissions levels of nitrous, carbon or sulfide oxides. A rotary engine operating on natural gas has demonstrated emissions of NOx of less than 1.0 gram per horsepower hour, compared to the 4.0 gram limit specified by the California Air Resources Board, for heavy-duty vehicles.

Bio-oil presents some unique problems for internal combustion engines. Metal corrosion and injector erosion and corrosion are problems that have been identified by others. The internal materials of the rotary engine are composed of chrome, stainless steel and ceramic composites. The engine itself is resistant to the corrosive properties of bio-oil. As yet, a corrosion resistant fuel injection system has not been designed, therefore the bio-oil will be emulsified using a technology developed by Ikura [1]. The bio-oil will be encapsulated in the diesel and should combust in a similar fashion to a heavy fuel. A parallel program is underway to develop the fuel delivery system for burning 100% bio-oil in a rotary engine.

Rotary International has successfully tested their engine design on gasified biomass and hence the engine can be directly connected to a gasifier. Since Encon's heated auger can also operate as a gasifier, testing will be conducted on the engine modified for biogas. Encon is presently experimenting with a 2 horsepower gasoline engine for small scale gasification testing prior to full scale tests on the larger rotary engine.

The estimated cost of electricity from an Encon pyrolysis – Rotary Power engine system is very competitive with electricity costs from existing large centralised power plants.

[1] Ikura, Michio, Siamak Mirmiran et al. Pyrolylsis liquid-in-diesel oil microemulsions. US Patent Number 5,820,640. October 13, 1998.